International Journal for Modern Trends in Science and Technology
Volume 10, Issue 11, pages 25-33.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol10issue11.html
DOI: https://doi.org/10.46501/IJMTST1011004

Seasonal Variation in Benthic Macrofaunal Diversity and Distribution in Ambuliyar River and Sethubavachatram Coastal Waters, Southeast India

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To Cite this Article
Selvarasu Mariyappan and Perumal Murugesan*, Seasonal Variation in Benthic Macrofaunal Diversity and Distribution in Ambuliyar River and Sethubavachatram Coastal Waters, Southeast India, International Journal for Modern Trends in Science and Technology, 2024, 10(11), pages. 25-33. https://doi.org/10.46501/IJMTST1011004

Article Info
Received: 29 October 2024; Accepted: 22 November 2024.; Published: 24 November 2024.

ABSTRACT

In the present study, benthic macrofaunal diversity and distribution in Ambuliyar River and Sethubavachatram coastal waters were studied and a total of 59 species of macrofauna consisting of three groups namely Polychaetes, Bivalve, and Gastropods were recorded with a maximum density of macrofauna (1650 Nos./m-2) in St-3. Among the four macrofaunal taxa, polychaetes topped the list with 49 species followed by Bivalves (6 species) and gastropods (4 species). Seasonally, the maximum number of macrofaunal species (36 species) was recorded at St-3 during post-monsoon, and the minimum (23 species) was recorded at St-5 during monsoon seasons. CCA and BIO-ENV (Biota-Environmental matching) analysis showed that the environmental parameters such as dissolved oxygen, salinity, w. pH, silt, sand, TOC, and Clay manifested as the best match (ρω = 0.942) in determining macrofaunal distribution in the surveyed stations. The maximum macrofauna diversity (3.467) and evenness (0.743) were recorded at St-3 and the maximum species richness was recorded (6.539) at St-5. The results of the present study would help to develop an understanding of the macrofaunal distribution based on physico-chemical parameters, which will form a reliable tool in bio-monitoring studies..

KEYWORDS: Macrofauna, benthos, indices, diversity, Ambuliyar River, Sethubavachatram coast.

1.INTRODUCTION

The estuaries are used as transport routes, they are fundamental for socio-economic development and improving the quality of life. At present, about 60% of the world's population lives along the estuaries and the coast Harris et al. (2016). Estuaries are highly productive ecosystems that protect from extreme winds and waves while serving as vital sources of nourishment as rivers

flow into the sea (Varadkar, 2024). Estuaries have a unique combination of physical features associated with their shape (semi-circular), catchment area connection to the sea, and tidal regime. Moreover, there is a great variety of human impacts and anthropogenic activities in both the estuary and its catchment area (Khedr et al., 1988; Saleem Raj et al., 2019). Benthic organisms play an important role in the detrital food cycle and also act as food for other fauna e.g. worms, snails, shrimps, mussels, barnacles, clams, oysters, etc., or by biological agents like macrobenthic organisms.

Macro-benthic organisms are one of the bio-indicators that are being utilized and promoted by various organizations (World Conservation Union, International Union for Conservation of Nature), as a means to handle bio-monitoring and evaluate human effects (Perera et al., 2011). Benthic macrofauna is an important group of organisms in the estuarine and coastal ecosystem feeding on microalgae and bacteria. They play a crucial role in bio-mineralization (Moghadasi et al., 2009) as well. Their diversity and distribution play a crucial role in assessing the health of ecological status in marine ecosystems. These organisms, including polychaetes, gastropods, bivalves, and amphipods, are essential in nutrient cycling, sediment stability, and energy flow (Urban-Malinga, 2014). Their sensitivity to environmental changes, combined with limited mobility, makes them valuable bio-indicators for detecting anthropogenic impacts.

To assess the ecological health of an estuary along the Tamil Nadu coast, a comprehensive study was conducted using the AMBI-AZTI Marine Biotic Index (Borja et al., 2000) and M-AMBI (Multivariate-AMBI) indices (Muxika et al., 2007). These indices, known for their robustness and effectiveness, are widely used in marine environmental health assessment studies. The AMBI index has been successfully applied across diverse ecosystems impacted by various environmental factors, demonstrating its versatility and reliability (Sigovini et al., 2013). The M-AMBI, an advanced multivariate version of AMBI, incorporates reference condition values and provides additional insights into the Biotic Index (BI), Diversity, and Species richness, making it a valuable tool for evaluating site disturbance and ecological status. Most of the studies on the macrofauna diversity in the Indian subcontinent have been done on the continental shelf (Sajan et al., 2010).

The diversity and distribution of benthic macrofauna, especially in regions under environmental pressure, provide insights into ecosystem functioning and resilience. In this study, an attempt has been made to document the diversity and assemblage of benthic macrofauna from Ambuliyar river and Sethubavachatram coastal waters, with particular attention to seasonal environmental variations.

2. MATERIALS AND METHODS

2. 1. Study area

In the present study, a seasonal sampling was carried out in Ambuliyar river and Sethubavachatram coastal waters (10°12'55.12"N and 79°17'4.57"E) for a period of one year from July 2022 (Pre-monsoon) to June 2023 (Summer). Five sampling sites were selected based on the depth (Table 1, Fig. 1). The monthly data were amalgamated for four seasons and the results are presented seasonally. The details of the sampling stations are given below:

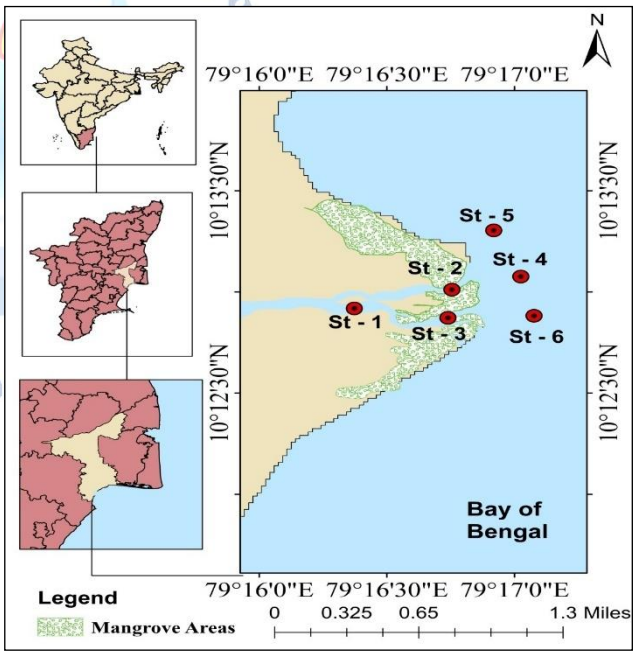

Table 1. Geographical locations of sampling stations in Ambuliyar river and Sethubavachatram coastal waters

Stations	Station Details
St-1	Fixed near non-Mangrove zone (NM-Z)
St-2	Fixed at *Avicennia* zone (AVI-Z)
St-3	Fixed at *Rhizophora* zone (RHI-Z)

St-4	Near the Ambuliyar Rivermouth
St-5	Fixed1.0kmrightsidefromAmbuliyarmouth
St-6	Fixed1.0kmleftsidefromAmbuliyarmouth

2. 2. Water and sediment analysis

Measurements of pH (pH pen, model LI-120, Eutech Instrument, Singapore), salinity (Refractometer, ATAGO, Japan), and temperature (hand-held mercury thermometer) were routinely done in bottom water at each sampling. Bottom water dissolved oxygen (DO) was evaluated by using Winkler's method (Strickland and Parsons 1972). Grain-size analysis of the sediments was performed by the pipette method (Krumbein and Pettijohn 1938). Sediment texture was analyzed using a sieve shaker (Retsch AS 2000) for sandy samples and a particle size analyzer (Malvern Hydro 2000G) for clayey samples. The biogenic calcareous portion in the sediment samples was removed using concentrated hydrochloric acid before texture analysis. The proportion of sand, silt, and clay was derived based on the quantity of different grain-sized portions in the sediment (Folk and Ward 1957). Total organic carbon (TOC in wt %) in sediment samples was analyzed by the wet oxidation method described by Walkley and Black (1934).

2. 3. Benthic macrofaunal analyses

In each station, three replicate samples were collected using Peterson Grab. This type of grab is considered to be the most efficient gear in obtaining good penetrative samples in shallow water environments. The grab employed was found to take a sample covering an area of 0.1m2. The procedure adopted for sampling was following the method of Mackie (1995). After collecting the samples, they were emptied into a plastic tray. The larger organisms were handpicked immediately from the sediments and then sieved through a 0.5 mm mesh screen. The organisms retained by the sieve were placed in a labeled container and fixed in 5–7% formalin. Subsequently, the organisms were stained with Rose Bengal solution (0.1 g in 100 ml of distilled water) for greater visibility during sorting. All the species were sorted, enumerated, and identified to the advanced possible level with the consultation of available literature. The works of Fauvel (1953); Day (1967) and http://www.marinespecies.org/polychaeta/ were referred for identification.

2. 4. Statistical analysis

Both environmental and macrofauna data were statistically analyzed using univariate, graphical/distributional, and multivariate methods available in the statistical software PRIMER (Ver. 7.0) (Clarke et al., 2016). Benthic macrofauna structure was described using the diversity index (H') (Shannon & Wiener, 1949), the Margalef's richness index (d) (Margalef, 1958), evenness (J') (Pielou, 1966), and dominance (D) (Simpson, 1949).

Principal component analysis (PCA) was also used to define the relationships among the physico-chemical parameters (i.e., temperature, salinity, dissolved oxygen, TN, TP, SiO3grain-size, soil pH, TOC,) and trend over sampling stations. Similarly, Canonical Correspondence Analysis (CCA) was applied to relate the relative abundance of macrofaunal taxa with linear representations of environmental variables. These routines were performed using the Vegan library package in the statistical language 'R' Ver.3.4.4 (Oksanen, 2018).

3. RESULTS

3. 1. Physico-chemical characteristics of water and sediment

The values of physico-chemical parameters of water and sediment are summarized in Figure 2. The temperature varied from 32°C at st-6 during Pre-monsoon 2022 and 25°C at st-1 during monsoon 2022. Salinity fluctuated between 15.0 and 35.5 ppt, with the minimum recorded at St-6 in the range of 4ppt during monsoon 2022 and the maximum recorded at St-4 in the range of 36ppt during Summer 2023. Water pH varied from 8.2 at St-1 during summer and 7.7 at St-6 during monsoon 2022. Dissolved Oxygen (DO) ranged from 3.45 mg/l at St-5 during summer 2023 and 5.18 mg/l at St-2 during Pre-monsoon 2022. Total Nitrogen varied from 20.50µmol/l at St-5 during Monsoon 2022 to 52.39µmol/l at St-1 during Pre-monsoon 2022. Total phosphate ranged from a minimum of 0.61 at St-6 and the maximum was 3.11 at st-3 during Pre-monsoon.

In the sediments, the TOC content ranged from 1.41 to 8.42mgC/g and the maximum was recorded at St-4

during pre-monsoon 2022 and the minimum was at St-1 during post-monsoon 2023. Sand content ranged between 1.35 and 75.57 %, with a maximum value recorded at St-1 during Pre-monsoon 2022 and a minimum at St-2 during Pre-monsoon 2022; silt content varied from 10.02 to 71.17 % with a maximum at St-5 during Pre-monsoon 2022 and minimum at St-2 in post-monsoon 2023 and the clay content in the sediment fluctuated between 5.89 and 54.53 % with maximum at St-1in pre-monsoon 2022 and minimum St-2 in post-monsoon 2023.

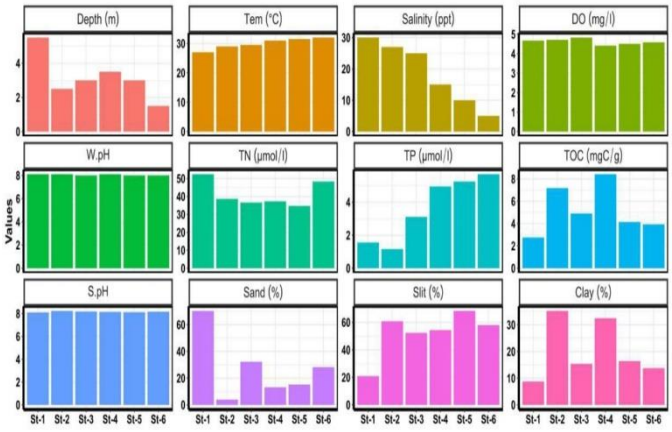

Fig. 2. Seasonal changes of environmental variables in Ambuliyar River and Sethubavachatram coastal waters.

3. 2. Benthic Macrofauna

In the present study, a total of 59 benthic macrofauna faunal species were recorded in Ambuliyar river and Sethubavachatram coastal waters during the study period. Of this total, polychaetes were found to be the most dominant group with 49 species followed by Bivalves 6 species and gastropods 4 species.

Among the polychaetes, Cirratulus chrysoderma, C. cirratus, Glycera longipinnis, G. unicornis, Gonidia emerita, Loimia medusa, Lumbrineris aberrans, L. inflate, Malacoceros indicus, Maldane sarsi, Namalycastis abiuma, Namalycastis indica, Neanthes glandicincta, N. dibranchis, N. polybranchia, Nereis capensis, Notomastus aberans, Onuphis eremite, Pista indica, Prionospio cirrifera, P. pinnata, P. sexoculata, Syllis gracilis, and Terebella ehrenbergi were found to be the common species. With respect to bivalves, Anadara granosa, Crassostrea sp., Meretrix casta, M. meretrix, Mytella strigata, Paphia sp. were found to be the common species. Similarly, Pirenella cingulata, Telescopium telescopium, Terebralia palustris, Umbonium vestiarium in gastropods were common species during the study period. The maximum abundance was recorded at station St-3 with 1650 Nos/m-2 during post-monsoon and the minimum was at St-5 with 900 Nos/m-2 during monsoon. Seasonally, the maximum number of macrofaunal species (36 species) was recorded at St-3 during post-monsoon, and a minimum (23 species) was recorded at St-5 during monsoon.

3. 3. Percentage contribution

The results of the percentage composition of various macrofaunal groups revealed that, in Ambuliyar river and Sethubavachatram coastal waters, the polychaete constituted the maximum with 48% of the total macrobenthic organisms and bivalves, gastropods, contributed 36%,16% respectively to the total macrofaunal species collected (Fig. 3).

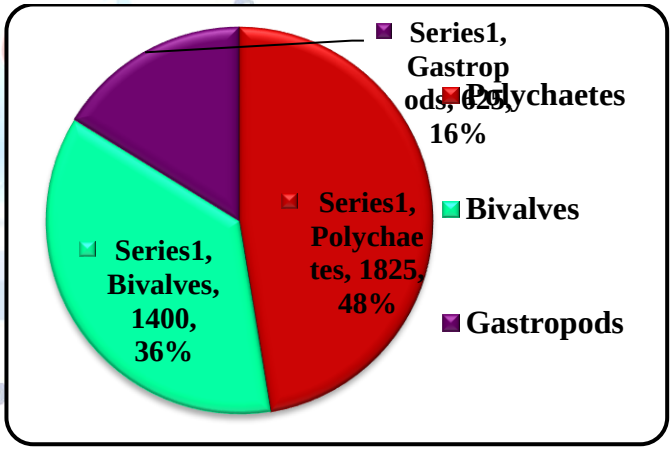

Fig. 3. Percentage contribution of macrofaunal groups recorded in various sampling stations of the Ambuliyar river and Sethubavachatram coastal waters

3. 4. Diversity Indices

Shannon diversity (H') index's lowest value was recorded (2.278) at St-5 during monsoon and the highest (3.467) was at St-3 during post-monsoon. Margalef species richness (d) lowest value was (3.817) at St-1 during monsoon and highest (6.539) at St-5 during summer. Pielou's species evenness (J') varied between 0.429 and 0.783 with the lowest value in St-4 during monsoon and the highest in St-2 during summer.

Simpson dominance index varied from 0.682 to 0.743 with the lowest in St-5 during monsoon and the highest in St-2 during post-monsoon (Table 2).

Table 2. Diversity indices Shannon diversity (H'); Margalef richness (d), Pielou's evenness (J'), and Simpson dominance (D)calculated for macrobenthos in Ambuliyar river and Sethubavachatram coastal waters

Stations	Shannon diversity (H')	Margalef richness (d)	Pielou's evenness (J')	Simpson dominance (D)
St-1	3.121	3.817	0.607	0.684
St-2	2.956	4.362	0.783	0.743
St-3	3.467	6.317	0.747	0.669
St-4	3.228	4.726	0.429	0.653
St-5	2.378	6.539	0.536	0.682
St-6	3.163	6.005	0.711	0.651

3. 5. PCA and CCA

The principal component analysis was performed using physicochemical parameters to set a well-defined distinction between the stations. The PCA plot revealed that St-2, St-4and St-5 showed high correlation with parameters such as DO, salinity, water pH, sand, evenness (J), and diversity (H'); while St-1 and St-3 negatively correlated with other parameters such as water silt, TN, TP and SiO3(Fig. 4).

Similarly, CCA analysis was done to find out the correlation between environmental parameters and species abundance, which revealed that the species such as Ancistrosyllis parva, Perenereis cultrifera, Nephtys capensis, Pisione oerstedi, Eunice antennata, E. indica, Cirriformia tentaculata, Pectinaria crassa, Anadara granosa, Crassostrea sp., Meretrix casta, M. meretrix, and Pirenella cingulata got positively correlated with temperature, W. pH, salinity, dissolved oxygen, sand, clay, and total organic carbon at St-2, St-4, and St-5. It was also evident that species such as Glycera unicornis, Syllis cirropunctata, Onuphis eremite, Pista indica, Prionospio pinnata, Syllis gracilis, Terebella ehrenbergi, Mytella strigata, Paphia sp., Telescopium telescopium, Terebralia palustris, Umbonium vestiarium were negatively related to the silt, TN, TP at St-1 and St-3 (Fig. 5).

Pearson correlation coefficient indicates a significant relationship between environmental factors, heavy metals, and species abundance in study sites. Station St-3, St-4, St-5, and St-6 were found to display positive correlation with environmental factor (temperature, W. pH, salinity, TN, sand, S. pH). Station St-1&St-2 showed negatively influential DO, TOC, clay, and Silt (Fig. 6).

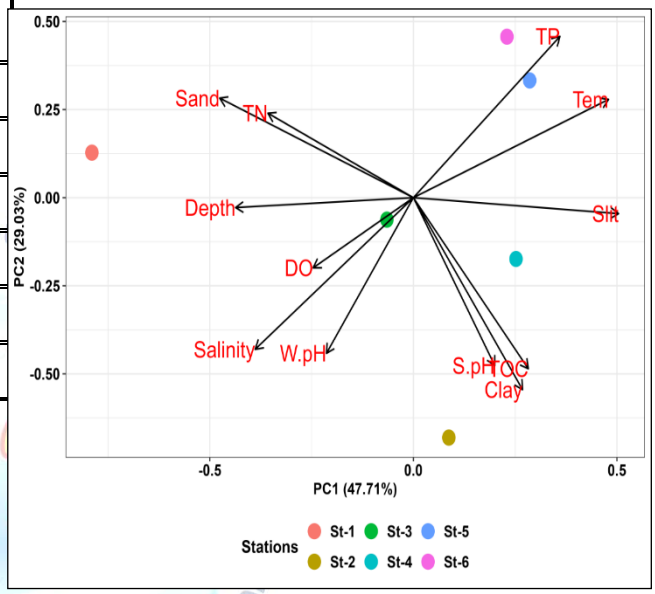

Fig. 4. Principal Component Analysis plot drawn for environmental parameters and macrofauna diversity in Ambuliyar river and Sethubavachatram coastal waters

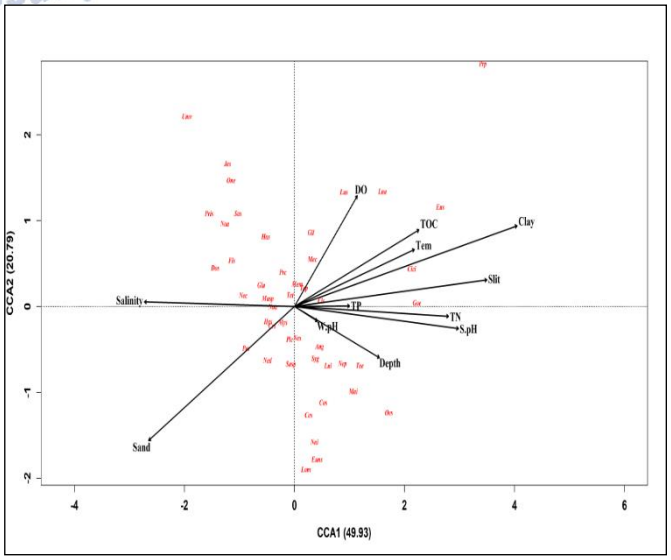

Fig. 5. CCA plot showing inter-relationship between macrofauna species against environmental variables

in Ambuliyar river and Sethubavachatram coastal waters

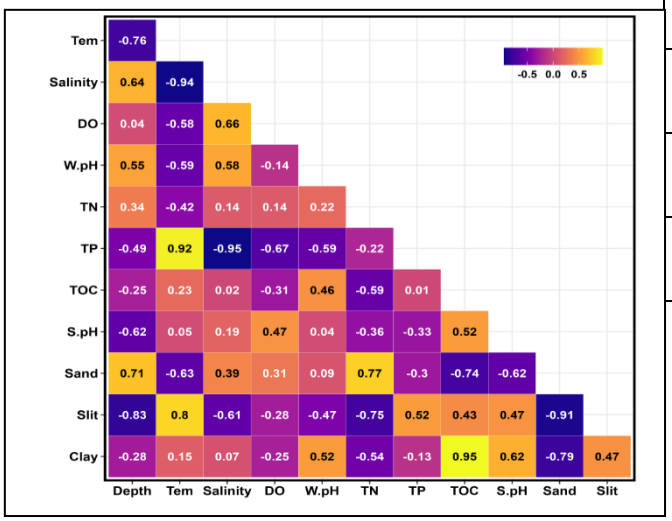

Fig. 6. Pearson correlation coefficient between physicochemical parameters

3. 6. BIO-ENV (Biota-Environment matching)

In the BIO-ENV procedure, which was employed to measure the agreement between the rank correlations of the biological (Bray-Curti's similarity) and environmental (Euclidean distance) matrices, ten environmental variables were allowed to match the biota. The parameters that significantly influenced the diversity and distribution of macrofaunal were salinity, W. pH, dissolved oxygen, total organic carbon, sand, silt, and clay were allowed to match the biota. Among the parameters, a combination of eight environmental parameters ($p\omega$ = 0.931) namely Dissolved oxygen, Salinity, W pH, Sand, Silt, TOC, and Clay manifested as the best match in the determination of benthic macrofaunal distributions followed by Dissolved oxygen, Salinity, pH, Sand, TOC, and Clay in the next level (Table 3).

Table 3. Harmonic rank correlations (rw) between macrofaunal abundance and environmental Similarity matrices in various stations of Ambuliyar river and Sethubavachatram coastal waters

No. of variables	Best variable combinations	Correlation ($\rho\omega$)
8	Dissolved oxygen –Salinity – W. pH – Silt - Sand – TOC - Clay	0.942
7	DO – Salinity – pH – Sand – TOC – Clay	0.922
6	Salinity – W pH – TOC – Clay - Sand –	0.853
5	W. pH– Clay – Salinity - TOC	0.892
5	DO – W pH – Clay – Salinity - TOC	0.746

4. Discussion

The composition of benthic invertebrates plays a vital role as an indicator of water quality because these organisms, unlike plankton, form stable communities in sediments, offering insights into long-term changes in water and sediment characteristics. Several abiotic factors, including temperature, pH, substratum, water depth, dissolved oxygen (DO), and predation, are known to influence the structure of macroinvertebrate communities (Tailing, 1976; Reice, 1980; Delince, 1992; Senthilkumar et al., 2002). In this study, significant variations in temperature, salinity, and pH were observed.

The water temperature ranged from 26.0°C to 31.5°C, pH fluctuated between 7.6 and 8.3, and salinity varied from 15.0 to 35.5 ppt. Higher values of these parameters were recorded at offshore stations during the summer, likely due to increased solar radiation and evaporation. In contrast, lower values were observed in nearshore stations during the monsoon, due to the influx of freshwater from land drainage. This trend aligns with findings from Sridhar et al. (2006) and Sundaramanickam et al. (2008). Dissolved oxygen (DO) ranged from 3.85 to 5.47 mg/l, with the highest values occurring at offshore stations during the monsoon and the lowest at nearshore stations during the post-monsoon season. The higher DO during the monsoon is attributed to increased freshwater influx into the area, while the lower DO values in summer can be linked to fluctuations in temperature and salinity, which affect oxygen dissolution (Vijayakumar et al., 2000; Murugesan et al., 2002; Saravanakumar et al., 2007; Kumar et al., 2022).

Organic carbon content in sediment is another key parameter influencing benthic ecology, reflecting organic pollution levels and ecosystem productivity. The

distribution of total organic carbon (TOC) followed the trend of sediment types, with higher TOC levels found in clay soil. During the summer, TOC was at its peak, especially in nearshore areas, with a maximum value of 10.64 mgC/g, and the lowest values were recorded during the wet season (6.32 mgC/g at offshore stations). These results support findings by García-Arberas and Rallo (2002) and Hasrizal et al. (2009), who also observed seasonal variations in organic carbon content. Coppola et al. (2007) noted that fine particles (<4μm) in the sediment typically carry 10-20% of organic carbon.

Seasonal variations in sediment composition are critical for understanding benthic ecology. The monsoon season saw the lowest levels of sediment organic carbon, possibly due to the mixing of terrestrial waste through floods and fishing activities (Veerasingam et al., 2014). The benthic species composition in this study was dominated by Polychaetes, followed by Crustaceans, Gastropods, Bivalves, and other groups. The dominance of polychaetes is likely due to their adaptability to diverse environmental conditions, as seen in previous studies (Kumar et al., 2022).

The density of macrobenthos showed marked seasonal variation with the lowest density recorded during the monsoon, a gradual increase during the post-monsoon, and a peak during the summer. This pattern is consistent with previous studies (Denadai et al., 2000; Thilagavathi et al., 2013). Diversity and evenness indices showed minimum values at nearshore stations during the monsoon and maximum values at offshore stations during the summer. The species richness and dominance were higher during the wet months, whereas they were lower in the summer and dry seasons. This aligns with findings by Kundu et al. (2010), Raveenthiranath (1990), and Palanisamy and Anisa (2013).

Principal Component Analysis (PCA) and Correlation Coefficients revealed strong correlations between salinity, temperature, and pH with the distribution and composition of macrofauna at the surveyed stations, consistent with the studies by Fajemila et al. (2015) and Sigamani et al. (2019). Canonical Correspondence Analysis (CCA) showed that temperature, pH, salinity, dissolved oxygen, sediment types, and total organic carbon strongly influenced benthic faunal diversity. Other parameters, such as water depth and dissolved oxygen, showed weaker correlations. These findings corroborate studies by Sivaraj (2014), Murugesan et al. (2018), and others, who reported similar environmental variables affecting benthic faunal distribution.

5. CONCLUSION

The present study provided baseline information about the diversity and distribution of benthic macrofaunal in Ambuliyar river and Sethubavachatram coastal waters. The present findings contribute additional knowledge on the influence of seasonal variation on the macrofaunal assemblage since there are few studies on this aspect in Indian coastal waters. Analysis of data undertaken with conventional tools like univariate and multivariate methods revealed the healthy nature of the coasts and species estimation showed that the sample size of the present study is quite adequate for the efforts taken to document all the meiofaunal species occurring in the surveyed stations. Moreover, this study also emphasized that DO, sediment texture, salinity, and pH are the most important factors in determining the distribution of macrofauna in Ambuliyar River and Sethubavachatram coastal waters. In conclusion, this study reinforces the significance of abiotic factors, such as temperature, salinity, and organic carbon content, in structuring benthic invertebrate communities. The seasonal and spatial variations observed in these parameters are crucial in understanding benthic ecology and water quality.

Acknowledgments

Authors are grateful to the Director & Dean, CAS in Marine Biology & authorities of Annamalai University for providing the necessary facilities. The author acknowledges gratefully the Ministry of Environment, Forests and Climate Change of the Government of India (MoEF&CC) for the financial support.

Conflict of interest statement

Authors declare that they do not have any conflict of interest

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